Impacts of Control Moment Gyroscope (CMG) Gear Slack on Spacecraft Pointing Performance

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Dylan Penn
Air Force Research Laboratory/
Space Vehicle Directorate

Eric Swenson
Air Force Institute of Technology/
Astronautical Engineering Department

Outline

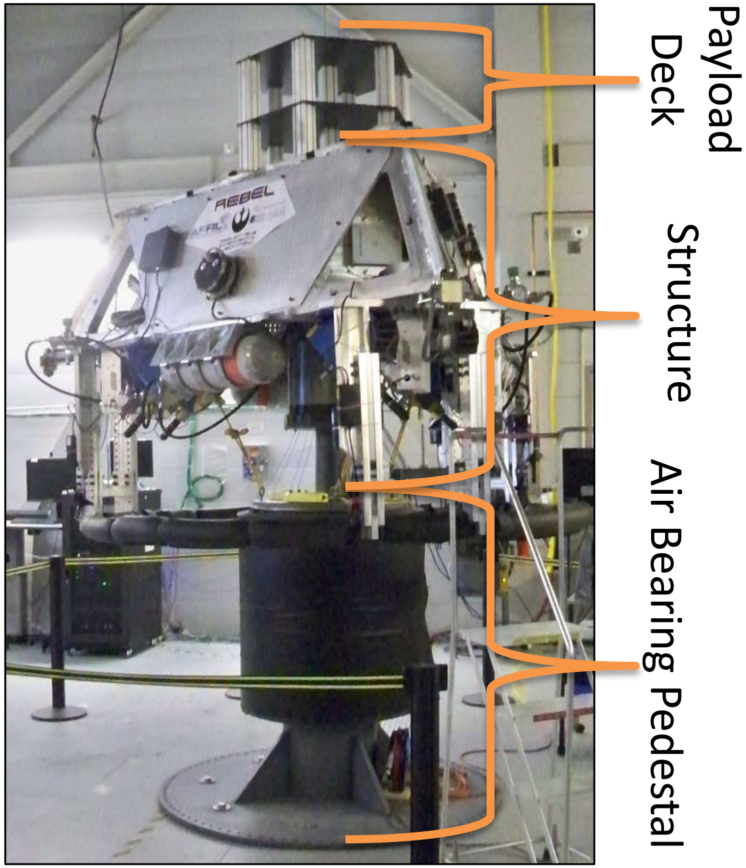
- Resilient Bus Experimental Laboratory (REBEL)
- REBEL CMGs
- Model Scenario
- Results
- Analysis
- Conclusions

REBEL spacecraft simulator testbed

REBEL

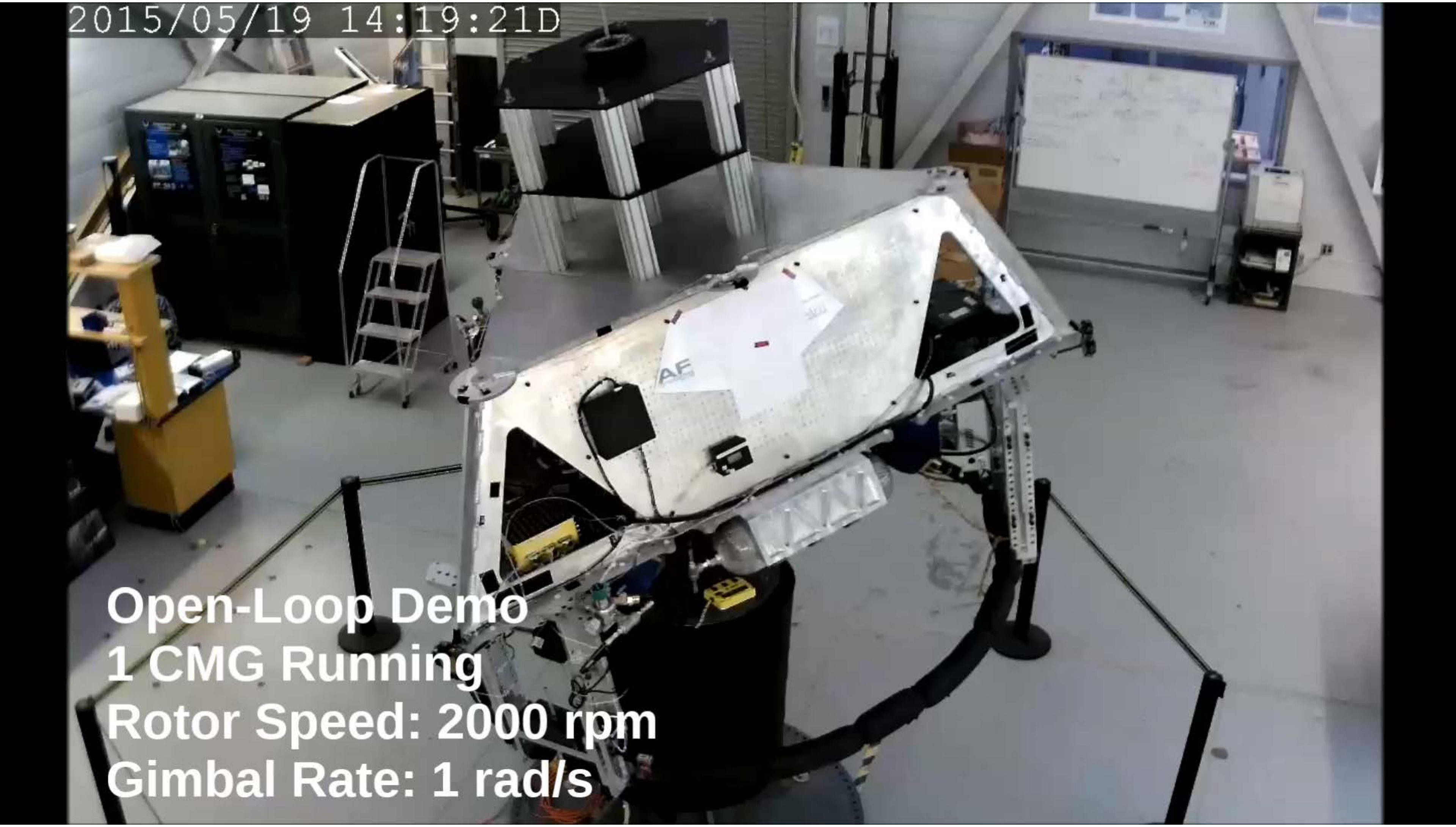
- Models sometimes impractical
  - Difficulty
  - Eg: fluid sloshing, structural flexing
- Spacecraft (S/C) simulators
  - *Testing Spectrum*

    Models S/C Simulators Experiments
- REBEL
  - Rotational spherical air bearing
  - Attitude control: CMGs, RWs, air thrusters
  - Attitude determination: IMU, gyros, PhaseSpace motion capture



REBEL spacecraft simulator testbed

CMG Open Loop Video



REBEL CMGs

- Built by AFIT
- Design objectives:
  - Lab-rated
  - Inexpensive
  - Modular (easily repairable)
- Gimbal motor
  - About 5°gear slack

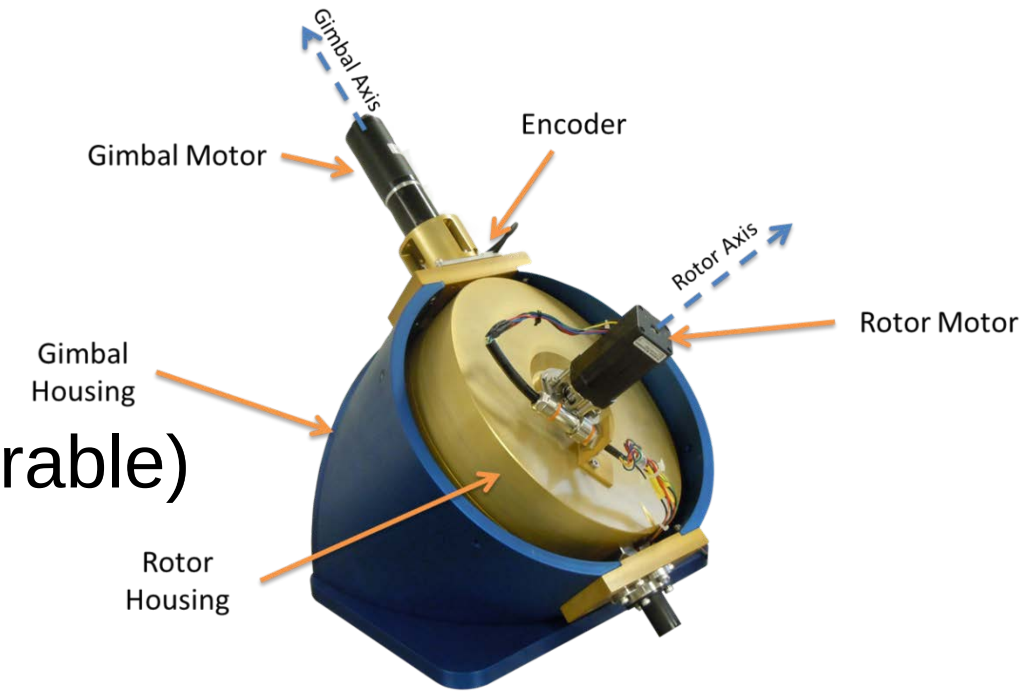


Figure 2: REBEL CMG with components labeled [2]

Objective: <u>To better understand the impacts of CMG gimbal gear slack on overall spacecraft attitude control performance</u>

Model Scenario

- S/C executes pointing maneuvers
  - Multiple-collect pass (i.e. Earth imaging)
  - Point-hold-repeat
- Target deck
  - 40 targets
  - All points lie on circle
- Simulation length: 640 sec
- 4-CMG pyramid array
- Same gear slack for all gimbals
  - Simulated 0° (control case), 5° (nominal), 10° (extreme)

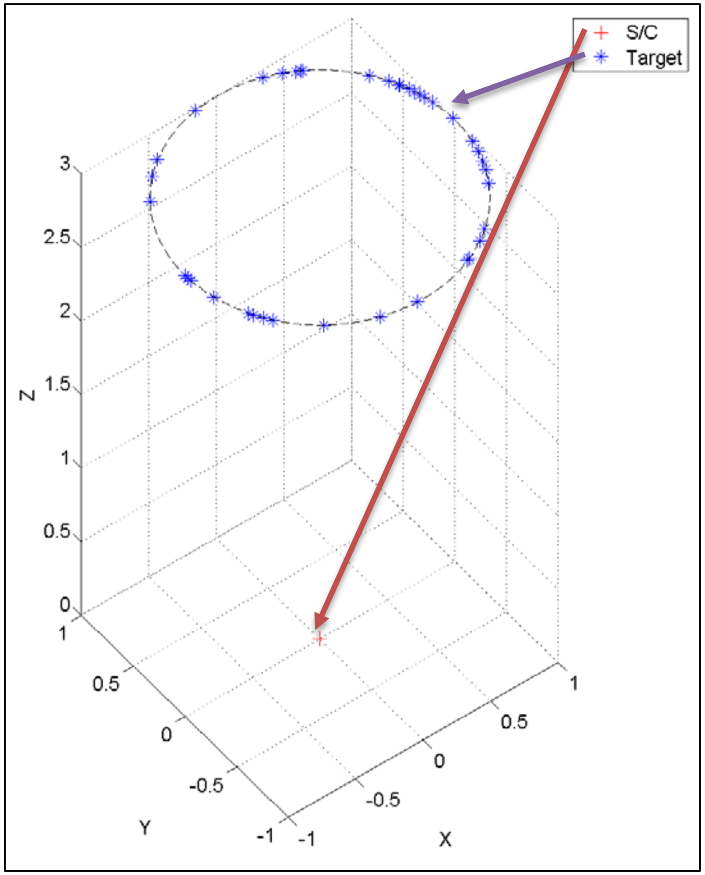


Figure 4: Pseudo-random target deck (40 targets)

Results (1/2)

- Gear slack behaves as expected
  - Gimbal (δ) lags motor (m)
  - Position hold on direction change

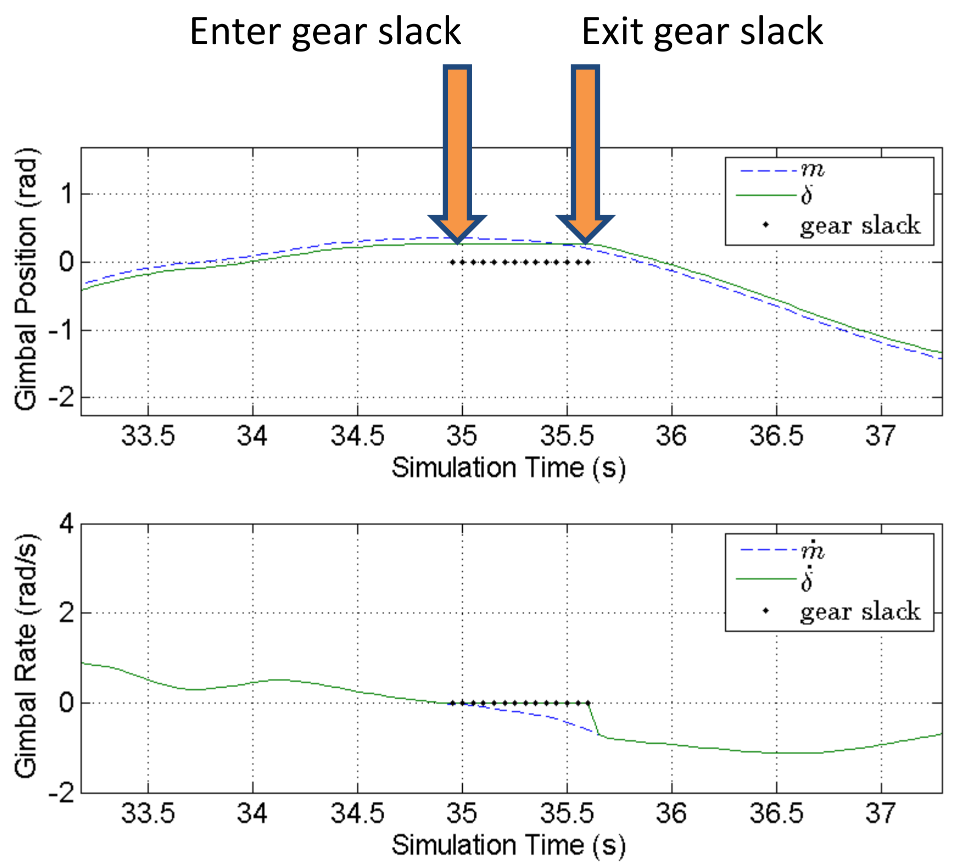
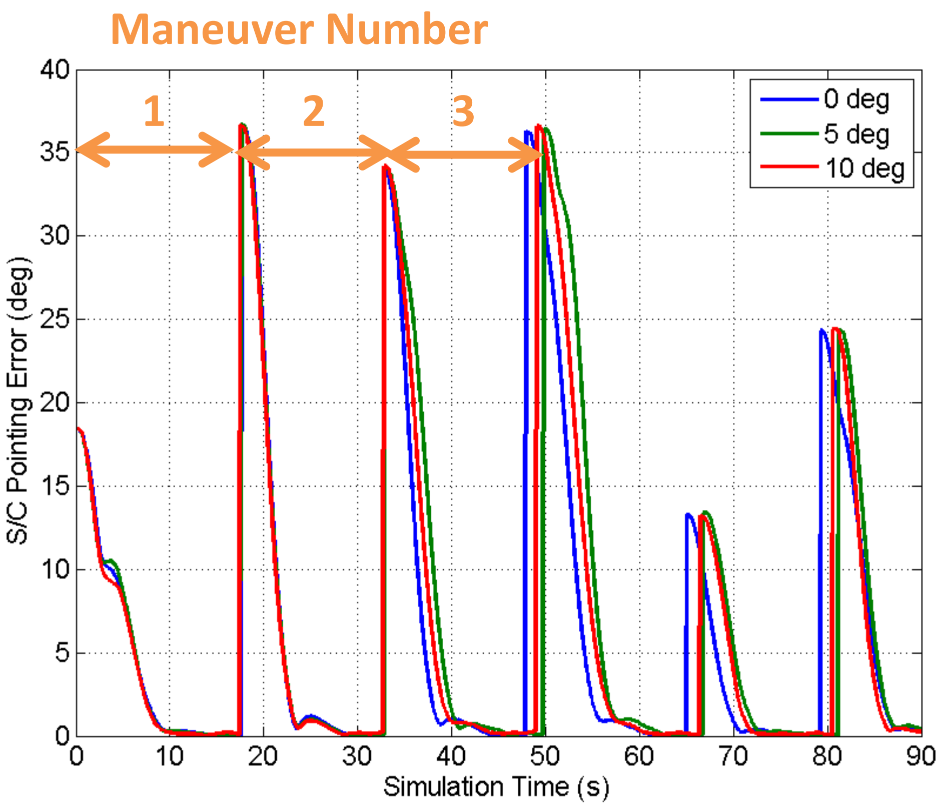


Figure 8: Zoomed-in gimbal data (10° gear slack)

Results (2/2)

- Gear slack affects maneuver duration
- Gear slack generally causes delay
  - Using 0° as control case



Analysis (1/2)

- Maneuver duration vs. maneuver size
  - Maneuver size: pointing error at time of target switch
- More variation with larger maneuvers (>20°)
  - For absolute and relative maneuver duration
- Gear slack does not affect small maneuvers

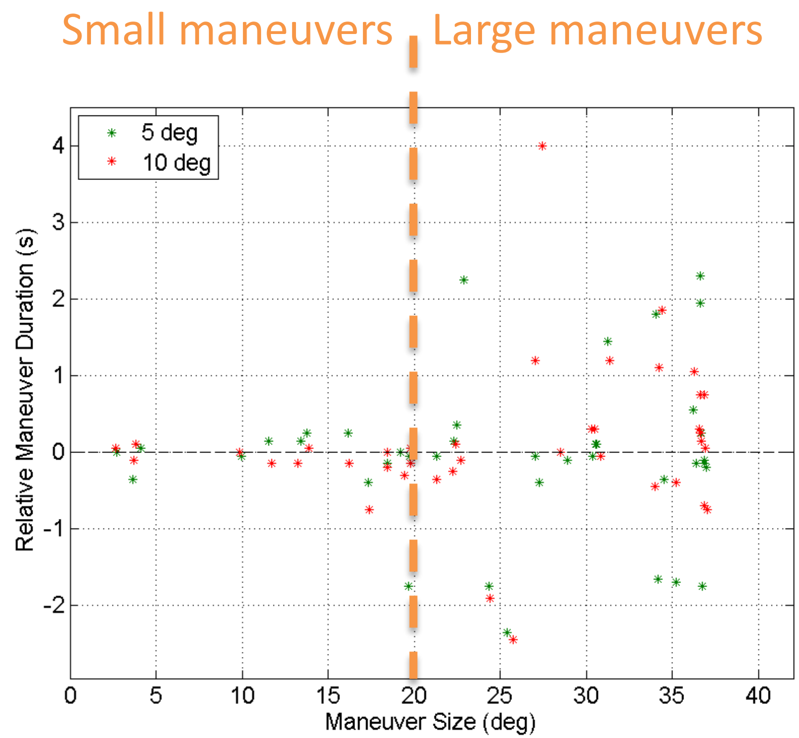


Figure 11: Maneuver duration relative to the control case (no gear slack)

Distribution A

Analysis (2/2)

- Stratify data into large and small maneuvers
- Gear slack:
  - Increases variance
  - *Slightly* decreases small maneuver duration
  - *Slightly* increases large maneuver duration
- No significant statistical differences

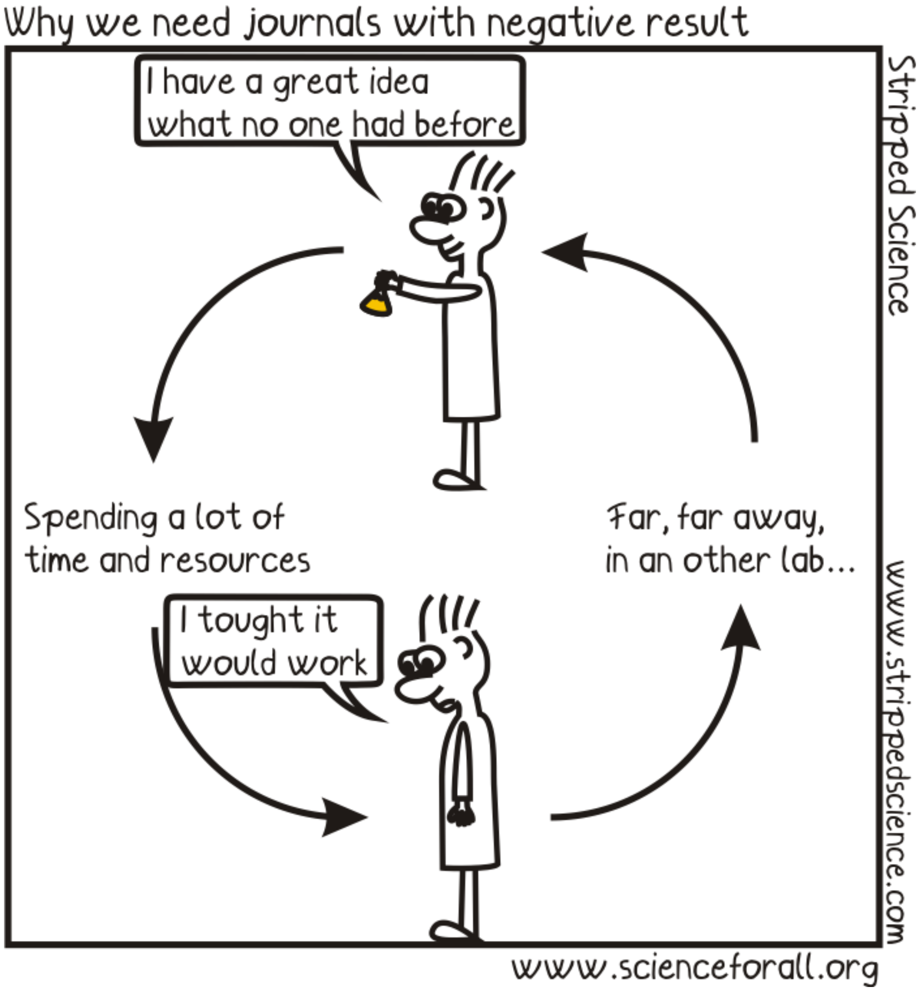
Table 4: Statistical results for relative maneuver duration from Figure 11

Gear Slack	Duration RMS (s) (Maneuver<20°)	Duration RMS (s) (Maneuver>20°)
5°	0.50	1.20
10°	0.24	1.20
	Duration STD (s) (Maneuver<20°)	**Duration STD (s) (Maneuver>20°)**
5°	0.50	1.23
10°	0.22	1.20
	Duration Mean (s) (Maneuver<20°)	**Duration Mean (s) (Maneuver>20°)**
5°	-0.14	0.02
10°	-0.12	0.23

Conclusions

- Small and large maneuvers impacted differently
- Different amounts of gear slack do not affect maneuver duration
  - No big differences in 5° and 10° test cases
- No significant affects due to gear slack

Questions?



http://blog.f1000research.com/2013/05/24/scientific-quality-in-negative-results-comments-please/

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Supplemental Slides

Model Structure

- 2 Loops
  - S/C control: 40 Hz
    - Based on hardware
  - Dynamics: 200 Hz
    - RK4 integrator
    - Fixed time step
- Vehicle pointing: PI
- CMG control (acceleration): P
- Gimbal and motor states tracked separately

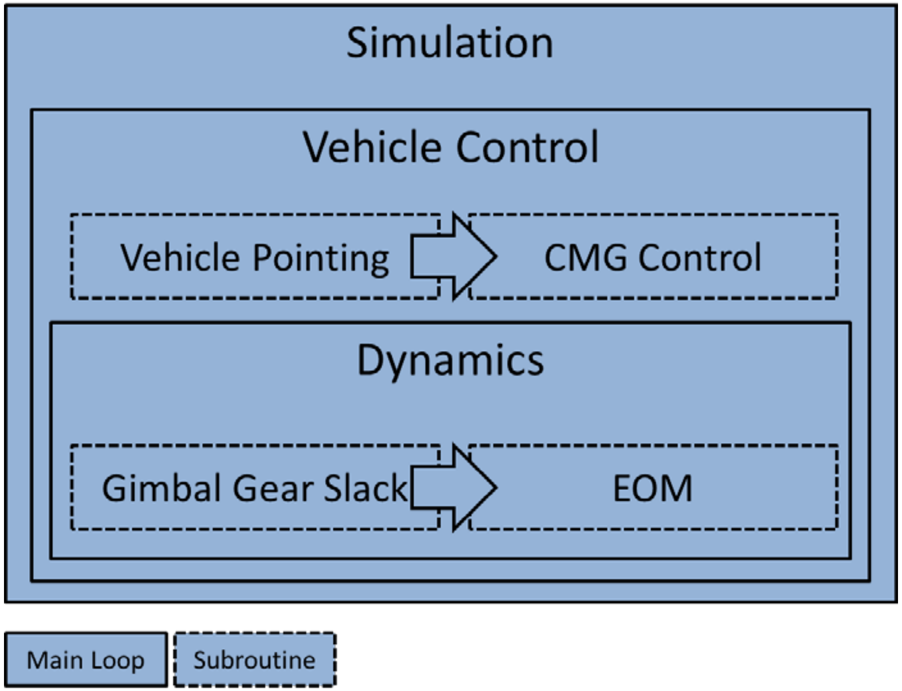

Figure 5: Graphic representation of REBEL model

CMG Jacobian

- 4-CMG pyramid array
  - Jacobian in Eq. 1

$$A = h_0 \begin{bmatrix} s\beta_1 s\delta_1 & -s\beta_2 c\delta_2 & s\delta_3 & -s\delta_4 \\ -s\delta_1 & s\delta_2 & s\beta_3 c\delta_3 & -s\beta_4 c\delta_4 \\ c\beta_1 c\delta_1 & c\beta_2 c\delta_2 & c\beta_3 c\delta_3 & c\beta_4 c\delta_4 \end{bmatrix} \text{ Eq. 1}$$

CMG Array

- 4-CMG pyramid array
- Gimbal inclinations β=45°
- Rotor momentum h_0=26.6 N-m-s
- Same gear slack for all gimbals
  - Simulated 0° (control case), 5° (nominal), 10° (extreme)

Future Work

- Compare results to experimental tests
- Run Monte-Carlo using larger target decks
  - Will refine statistical evidence
- Incorporate rate-tracking maneuvers
- Use control-centric metrics for analysis
  - Settling time, rise time, percent overshoot
- Correlate gimbal angle arrangements with maneuver durations